WATER RESOURCES RESEARCH GRANT PROPOSAL

Project ID: 2005MT56B

Title: STUDENT FELLOWSHIP: The effects of glacial meltwater chemistry, microbial processes and climate change on nitrate loading and ecological response in high alpine aquatic systems

Project Type: Research

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Abstract

Problem Statement:

Mountain ecosystems in the western United States are showing the early effects of change brought on by climate warming, drought, and atmospheric deposition. The most sensitive ecosystems, those most likely to be early warning indicators of regional and global changes, are found in the alpine regions, such as areas above treeline in Grand Teton National Park (GRTE) and Glacier National Park (GLAC). As stewards, we need sound science and research to understand how these changes will affect the resources that we protect, such as alpine soils and vegetation (including rare plants), lake and stream water quality and quantity, and downstream biota, such as fish and amphibians. The supply of water provided by glaciers and snowfields is also a buffer against large wildfires, such as those that swept through GLAC in 2003.

Change begets change. And the changes in runoff from glaciers and snowfields in the alpine will spawn change in the physical and chemical characteristics of both high-elevation and mid-elevation lakes and streams. For instance, loss of late-summer glacial flow in GRTE is already affecting flows in lower elevation streams and even in the Snake River. This reduced flow has altered riparian communities and changed the operation of Jackson Lake dam. As a result, less water is flowing to irrigators in Idaho who have water claims on the Snake River after it leaves GRTE. Moreover, the loss of large amounts of glacial mass in GLAC during the last two decades has modified vegetation structure and stream water quality at high elevations and in the subalpine.

The results of my master's thesis research suggested that the acid neutralizing effect of limestone bedrock and high nitrate from talus fields affect the basin water chemistry at sites in GRTE. NO_3^- concentrations in surface waters were high in areas not underlain by limestone and even higher in glacier-fed lakes. Generally, NO_3^- isn't a player in the geochemical composition of dilute mountain waters, but late-season NO_3^- values soared to 20 $\mu eq L^{-1}$ in several of the study lakes. And high NO_3^- increases a waterbody's sensitivity to acidification and eutrophication. Therefore, these areas are of special concern. Similarly, the numerous "namesake" glaciers in GLAC are eroding at a rapid rate, with little to no information about how the chemistry and base flow of outflow streams and their biota may be affected.

Glacial erosion processes and biogeochemistry of alpine talus environments in GRTE study basins may also be responsible for seasonal increases in NO_3^- concentrations in glacier-fed lakes, which in turn decrease the ANC. In both parks we have little information on subglacial hydrological systems, and how the biogeochemistry under glaciers is affecting lake and stream chemistry and flow. Research on glaciers in Europe shows that the increased physical weathering in glacial areas enhances chemical processes in glacial environments. The contribution of snowmelt and icemelt to the chemical composition of surface waters in glacially-fed systems is directly related to the routing of these waters along different flowpaths.

In addition to glacier meltwater chemistry, the presence of soil pockets, the thawing of frozen soils, and the presence of nitrogen-fixing cyanobacteria (in mosses and lichens) within the flowpath of high alpine hydrologic systems may also contribute to the nutrient enrichment of surface waters. Soil is sticky. And atmospherically-deposited solutes may collect in the soil for months, years, or even decades. Recent isotopic studies have shown that stream export of sulfate and nitrate is often dominated not by new atmospheric inputs, but by a fraction that has undergone transformations during storage in the soil. Similarly, a growing body of evidence suggests that microbial activity occurs within a spectrum of glacial environments, and that glacial rock flour is a significant source of N and P to these glacial ecosystems.

Physical weathering increases chemical weathering rates; increased surface area increases the chemical reactions between bedrock material and percolating water. In glaciated landscapes, the grinding action of the glacier creates rock debris that is more chemically reactive than the bedrock from which it is derived. Freeze-thaw weathering of bedrock outcrops creates talus slopes that are similarly more reactive, which is particularly effective in mountain environments with large areas of exposed bedrock and strong seasonal temperature differences. Many of the basins included in the GRTE study contain young debris created by a combination of glacial activity and physical weathering.

The increased weathering associated with the presence of rock debris can either help or hinder a waterbody's buffering capacity, depending on the bedrock characteristics. For example, in a 1985 study of GRTE lakes, Gulley and Parker (1986) noted that the only significant difference in solute chemistry among survey lakes was the elevated Mg^{2+} in Schoolroom Lake. Schoolroom Lake is located below Schoolroom Glacier, which is situated on limestone bedrock. Glacial abrasion of the limestone bedrock apparently contributed to the buffering capacity of Schoolroom Lake. NO_3^- concentrations in talus, however, contributed to NO_3^- in stream water in the Green Lakes Valley of the Colorado Front Range (Williams et al., 1997). Talus slopes contain areas of sand, clay, and organic material that sometimes support patches of tundra-like vegetation, which may affect the N cycle. Williams et al. hypothesized that the increased surface area of talus, and the increased residence time of water flowing through talus fields, results in increased NO_3^- concentrations in surface waters. Similar conclusions were made in the Andrews Creek watershed in 2002 (Sickman et al., 2003). In situations where talus occupies a significant proportion of a watershed, N-enrichment may be a greater problem for water quality than acidification from atmospheric deposition.

The results of the 2002 study suggested that both mechanisms – the acid neutralizing effect of limestone bedrock, and high nitrate from talus fields – affect the basin water chemistry at sites in GRTE. Three of the study basins that had limestone bedrock also had high proportions of young debris, and ANC values were relatively high, suggesting that a similar mechanism to that proposed by Gulley and Parker (1986) is also controlling the ANC in these lakes. However, watersheds without limestone but with a large amount of young debris had some of the lowest ANC values. Snowpack studies have shown that the neutralizing effect of Ca^{2+} is sometimes overcome by increases in NO_3^- and SO_4^{2-} (Mast et al., 2001), which is illustrated by lower pH values (Turk et al., 2001). The results of the GRTE study indicate that, in watersheds without limestone, high NO_3^- increases the sensitivity to acidification.

Past studies have shown that Ca/Na ratios increase with increasing physical disturbance and reach a maximum in glaciated areas (Henriksen, 1980; Stauffer, 1990). In GRTE, the highest Ca/Na ratios were recorded in lakes that had large percentages of young debris, but these lakes also resided in areas underlain by limestone. Therefore, lakes in these basins had sufficient buffering capacity. The relationship, however, between Ca/Na ratios and juvenility observed in other areas did not apply in glacier-fed lakes in granitic basins. For example, one glacial-fed lake had a Ca/Na ratio of approximately 16 and was 37% young debris (comparable to sampled lakes residing in limestone basins) but lacked limestone deposits (47% granite, instead). These results suggest that Ca/Na ratios in GRTE lakes are more dependent on bedrock geology than on the presence of juvenile terrane with large amounts of young debris.

Glacier dissolution in GRTE study basins may be responsible for seasonal increases in NO_3^- concentrations in glacier-fed lakes, which in turn decreases the ANC. One sampled glacial-fed lake had a mean Ca^{2+} concentration of 50.9µeqL-1 but NO_3^- and SO_4^{2-} concentrations were high (20.1 µeq L-1 and 12.3 µeq L-1, respectively), resulting in an ANC value of 42.5 µeq L-1. In contrast, a neighboring lake that didn't reside in a glacial-fed basin had a mean Ca^{2+} concentration of 68.5µeq L-1, a mean NO_3^- concentration of 0.4 µeq L-1, and a mean SO_4^{2-} concentration of 13.7 µeq L-1. The ANC value for this lake was 110.3 µeq L-1.

Research on subglacial hydrological systems is limited. Current studies have shown that chemical processes in glacial environments are not inhibited by limited soils and vegetation and low temperatures as was originally thought, but are enhanced by the increased physical weathering in glacial areas (Brown, 2002). The contribution of snowmelt and icemelt to the chemical composition of surface waters in glacially-fed systems is directly related to the routing of these waters along different flowpaths (Tranter et al., 1997; Mitchell et al., 2001). Studies conducted at the base of Haut Glacier d' Arolla in Switzerland suggested that high NO_3^- concentrations in boreholes were representative of snowmelt waters draining through a subglacial hydrologic system – a delayed flow. Therefore, the chemistry of waters draining through alpine glaciers is dependent on flow path and the long-term storage of snowpack (Tranter et al., 1997).

Managers need to understand the complexities change in the alpine zone– both biochemical and hydrological – to better manage resources, including aquatic biota, riparian vegetation and sport fisheries. This project will build on a completed study of lake chemistry in the alpine zone and take into account the interactions of atmospheric deposition, change in runoff from glaciers and snowfields, and changes in the way soils and talus interact with precipitation and snowmelt. This fundamental knowledge of alpine ecosystems is critical to our understanding of how to manage resources under changing climate and air deposition conditions.